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Improving control over the impulse for reward: Sensitivity of harmful alcohol drinkers to delayed reward but not immediate punishment

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ABSTRACT

Background: Cognitive control dysfunction has been identified in dependent alcohol users and implicated in the transition from abuse to dependence, although evidence of dyscontrol in chronic but non-dependent 'harmful' alcohol abusers is mixed. The current study examined harmful alcohol users response inhibition over rewarding stimuli in the presence of monetary reward and punishment, to determine whether changes in sensitivity to these factors, noted in imaging studies of dependent users, influences impulse control. *Method*: Harmful ($n = 30$) and non-hazardous ($n = 55$) alcohol users were administered a Monetary Incentive Go/No-go task that required participants to inhibit a prepotent motor response associated with reward. *Results*: Harmful alcohol users showed a significantly poorer ability to withhold their impulse for a rewarding stimulus in the presence of immediate monetary punishment for failure, while retaining equivalent response inhibition performance under neutral conditions (associated with neither monetary loss or gain), and significantly better performance under delayed reward conditions. *Conclusions*: The results of the present study suggest that non-dependent alcohol abusers have altered sensitivity to reward and punishment that influences their impulse control for reward, in the absence of gross dyscontrol that is consistent with past findings in which such performance contingencies were not used. The ability of delayed monetary reward, but not punishment, to increase sustained impulse control in this sample has implications for the mechanism that might underlie the transition from alcohol abuse to dependence, as well as intervention strategies aimed at preventing this transition.

1. Introduction

Young people 'at-risk' of later drug addiction demonstrate subtle, but significant, abnormalities in the neural mechanisms underlying reward processing and impulse control (McNamee et al., 2008; Tarter et al., 2003, 2004). Such impairments are also evident across addicted populations (Yucel et al., 2007) and they are similarly predictive of poor treatment outcomes, especially relapse during abstinence (Carpenter et al., 2005). While contemporary neurobiological models highlight the importance of such factors in the development of addiction (Dawe and Loxton, 2004; Goldstein and Volkow, 2002; Jentsch and Taylor, 1999; Kalivas and Volkow, 2005; Naqvi and Bechara, 2009; Paulus, 2007), these processes remain poorly understood.

Of particular interest to the current study was examining cognitive control, in the form of response inhibition, over rewarding stimuli in the presence or absence of an immediate aversive outcome. Previous research has typically focused on how individuals implement control over an overlearned response, when failure to do so results in an immediate punishment (typically a monetary penalty). While this type of control is representative of some real-world situations it does not adequately capture that required for many situations involving rewarding stimuli. For example, attempting to abstain from alcohol requires a person to inhibit the impulse to drink alcohol, which if ingested would be immediately rewarding, in preference to a longer term more abstract reward (e.g., improvement in health). When a person fails to inhibit an overlearned behaviour like this, there is no immediate punishment. While negative outcomes may follow at some point in the future, and have differing degrees of relation to the failure to inhibit (e.g., withdrawal, relationship breakdown, cirrhosis), the type of control required to inhibit the overlearned response is different to the immediate reward/punishment tasks previously used in the cognitive literature.

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Recent studies have demonstrated the importance of understanding the influence of reward and punishment contingencies to inhibitory control in drug users. For example, impulsive decision making for reward in drug abusing populations has been identified using the delay discounting procedure, where smaller, but immediate, rewards can be chosen in preference to larger delayed rewards (Bickel and Marsch, 2001; Field et al., 2007; MacKillop et al., 2011; McDonald et al., 2003; Mitchell et al., 2005; Monterosso et al., 2001; Petry, 2001). However, the results are not consistent across studies using this task (Fernie et al., 2010; Kirby and Petry, 2004; MacKillop et al., 2007), and do not appear to relate to alcohol use in non-dependent drinkers (Pryor and MacKillop, 2009). Other results from alcohol abusing populations have indicated that identifying inhibitory control deficits with tasks such as the Stop-signal and Go/No-go is particularly sensitive to whether inhibitory control performance is rewarded or punished (Colder and O'Connor, 2002; Kamarajan et al., 2005), and may be too insensitive for non-dependent populations in the absence of punishment for inhibitory control failures (Fernie et al., 2010; Field et al., 2008; Murphy and Garavan, 2011; Nederkoorn et al., 2009).

In combination with heightened reward sensitivity (Kambouropoulos and Staiger, 2001; O'Connor and Colder, 2005), drug dependent participants show a reduced sensitivity to punishment in their behavioural performance (Bechara et al., 2002; Ersche et al., 2005; Fridberg et al., 2010; Goudriaan et al., 2008; Grant et al., 2000). Neuroimaging studies of dependent drug users have also shown a diminished neural response to monetary loss (Beck et al., 2009; Bjork et al., 2008a,b; Wrase et al., 2007), in both sub-cortical 'limbic' regions such as the striatum and cortical regions such as the anterior cingulate cortices. These studies have typically not examined the consequences of such a reduced loss-response to subsequent behaviour (Hommer et al., 2011).

The use of punishment to shape appropriate behaviour is a key aspect of clinical (and criminal law) interventions for drug abuse and addiction, and its reduced effectiveness with drug abusers has widespread clinical, public health and law enforcement ramifications. Using a modified Go/No-go response inhibition paradigm that required participants to inhibit a prepotent motor response associated with reward we aimed to examine the relationship between alcohol abuse and control over a rewarding response in non-dependent alcohol abusing participants. To simulate the kind of beneficial behavioural outcome produced by successful abstinence, reward for successful inhibitory control took the form of delayed monetary gains that were the product of the highest number of consecutive successful response inhibitions across a large block of trials. A larger reward was gained by exerting control over a smaller, but immediate, reward-related stimulus during multiple, successive trials. This condition was repeated twice: the Immediate Punishment (IP) condition imposed an immediate monetary penalty for inhibitory failures, whereas the Delayed Reward (DR) condition did not punish inhibitory errors, instead participants received the reward previously associated with the stimulus response.

The aim of these contingencies was (1) to examine the influence of delayed reward on inhibitory control over immediate reward-related stimuli (when compared to non-reward stimuli), in the presence or absence of punishment; and (2) the influence of alcohol abuse behaviour on the interaction between reward, punishment and inhibitory control. The rationale for examining harmful alcohol drinkers was twofold, firstly we wanted to study the relationship between these variables in a non-dependent sample (Scaife and Duka, 2009), and because of the high proportion of the Australian alcohol drinkers who consume at harmful levels (AIHW, 2008) that are at-risk for developing dependence (Goudriaan et al., 2011; Rubio et al., 2008; Verdejo-Garcia and Bechara, 2009).

2. Methods

2.1. Participants

One hundred and twenty nine participants (71 female, mean age 26.2, range: 18–45) were recruited from the University of Melbourne Parkville campus and experimenter networks. Participants were screened to exclude those currently taking psychotropic medications, current or past dependence on nicotine (Fagerström Nicotine Dependence Test; Heatherton et al., 2006), abusing drugs other than alcohol (Drug Abuse Screening Test; Skinner, 1982), or with a current or past history of neurological or psychiatric illness. All participants provided informed consent and the project was approved by the University of Melbourne's Human Ethics Committee for meeting the standards for ethical research prescribed by the National Health and Medical Research Council. Participants were reimbursed for time (AUD$10 for the 60–75 min testing session) and received monetary rewards related to their task performance (range = AUD$ 22–41).

2.2. Assessment measures

2.2.1. Alcohol Use Disorders Identification Test (AUDIT). Levels of alcohol consumption were measured by administration of The Alcohol Use Disorders Identification Test (AUDIT; Saunders et al., 1993). We categorized participants into harmful and non-hazardous drinking groups based upon their total score on the AUDIT, with scores of 16 and above ($n = 30$) categorized as harmful and scores of less than 8 ($n = 55$) as non-hazardous. This categorization is based upon the World Health Organization's guidelines, which in turn is based upon population normative data for the AUDIT questionnaire, that identifies 'harmful' alcohol use (Babor et al., 1992, 2001) and is incorporated into the ICD-10. Scores of greater than 16 are considered 'harmful': "This is a pattern of alcohol consumption that is already causing harm, either physical or mental", whereas scores between 8 and 15 represents 'hazardous use': "that increases the risk of harmful consequences for the user . . .despite the absence of any current disorder in the individual user" (Babor et al., 2001). The distinction between potential and current alcohol-related harm was important to the current study, along with the desire to recruit participants who were significantly above the AUDIT mean for the typical University sample, who have a mean score of approximately 10 (see also (Heather et al., 2011) for comprehensive data from UK University students). These categories also conform to the Australian National Health and Medical Research Council 2009 guidelines to reduce health risks from drinking alcohol. The demographic and drug use behaviour of the two groups are presented in Table 1.

2.2.2. Monetary Incentive Go/No-go Task (MI-GNG). Participants completed a Go/No-go task designed to assess inhibitory control under varying reward/punishment conditions (Fig. 1). All aspects of stimulus delivery and response recording were controlled by E-Prime software (version 2.0, Psychology Software Tools, Pittsburgh, PA), running on a laptop PC (Intel 2 GHz, 256 mb Nvidia Video Card). The task consisted of three types of trials: Go, No-go and Money trials. Go trials presented a series of white non-repeat double-digit numbers (different, e.g., 21, 23 but not 22), centrally on a black background for 750 ms, followed immediately by a 1250 ms interstimulus interval (ISI) presenting only the black background. Participants were asked to respond to Go trials by making a single button press response as quickly as possible upon Go trial presentation.

Money trials presented repeat double-digit numbers (e.g., 11, 22 or 33) and required participants to make a single button press response as quickly as possible. The stimulus was presented for 750 ms, followed by a feedback screen for 750 ms and blank-screen ISI (500 ms). Money trials paid monetary rewards in proportion to how quickly the participant responded to the stimulus. No-go trials were pseudo-randomly interspersed throughout the Go trials.

The No-go stimulus was presented for 750 ms, followed by a 1250 ms ISI and then a 1000 ms feedback screen. Participants were informed prior to the beginning of each block which repeat double-digit number (e.g., 11, 22, 33) was designated as the No-go stimulus for the block of trials. Participants were asked to withhold their button response upon presentation of the No-go trial.

Two different repeat double-digit numbers were presented as Money trial stimuli for each block. In order to maximize the recency and prepotency of the association between the No-go stimuli and monetary reward, the No-go stimulus for each block was selected from one of the two repeat double-digit Money trial stimuli from the block preceding it. An exception was made for a Neutral condition in which non-repeat double-digit numbers were employed as No-go trials, i.e., 31 and 71.

Immediate feedback on performance accuracy and amount gained or lost was provided during the feedback screen that followed Money and No-go trials. Successful button presses for a Money trial stimulus provided an immediate monetary reward with a maximum value of 40c (AUD). The monetary reward for Money trials was calculated according to the response time (RT) during the 1000 ms response window duration (RT < 250 ms = 40c; <300 ms = 20c, <350 ms = 10c, >400 ms = 0). Performance accuracy feedback was also provided during the ISI period following successful No-go trial response inhibition. However, rather than receiving an immediate reward for successful inhibition during the No-go trial, participants were provided with monetary reward at the end of each block based upon the highest number of consecutive successfully inhibited No-go trials during the block, multiplied by 40c. For example, if within one block (160 trials), the highest number of

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Table 1
Demographic and alcohol use data for the total sample ($n = 129$), including Harmful ($n = 30$) and Non-Hazardous ($n = 55$) sub-groups.

	Total		Non-Hazardous		Harmful	
	M	*SD*	*M*	*SD*	*M*	*SD*
Age	26.2	6.6	26.4	7.3	28.4	6.6
Years of education	15.5	2.7	16.0	2.3	15.1	2.8
Gender (F:M)	71:58		40:15		11:19	
AUDIT	9.7	6.8	3.7	2.1	19.4	4.5
Alcohol use duration (years)	11.0	9.0	11.3	12.6	13.4	5.8
Alcohol consumption (standard drinks p/week)	9.9	8.8	3.1	3.0	18.4	8.7

Note: A 'standard drink' is 10 g of alcohol.

successful consecutive response inhibitions was seven, the participant was awarded \$2.80 (7×40c). Immediate feedback for successful inhibition of individual No-go trials informed participants that no reward had yet been accrued.

Three experimental conditions, Delayed Reward (DR), Immediate Punishment (IP) and Neutral, were administered to participants in a pseudorandom order. The conditions were differentiated by their contingencies relating to response inhibition failure during No-go trials. During the IP condition (Fig. 1b), feedback during the ISI period for No-go trials indicated a 40c punishment for failed inhibition. During the DR condition (Fig. 1a), failure to inhibit during a No-go trial did not result in a monetary punishment. Instead, feedback during the ISI period signalled performance failure and a monetary reward commensurate with RT, thereby remaining consistent with the response–reward relationship experienced during Money trials. During the Neutral condition, no monetary reinforcement was applied to inhibition success or failure, only Money trials were rewarded.

Three consecutive blocks of both IP and DR conditions were presented to participants, with a Neutral condition block preceding both sets of conditions. The presentation order of IP and DR blocks was counterbalanced across participants to control for order effects. Each block comprised of 120 Go, 20 No-go and 20 Money trials, all of which were pseudo-randomly presented such that No-go and Money trials were always separated by at least two Go trials. The two-digit stimuli were also differentiated across blocks and conditions, with digits 11–44 (inclusive) used for DR blocks and 55–88 used for IP blocks. Same-digit stimuli were rotated across the four blocks (Neutral, then 3 blocks of IP or DR), so that one of the two same-digit stimuli used for Money trials during each block was used in the subsequent block as a No-go stimulus. This feature maximized the recency of reward association with a stimulus. Similarly, a same-digit number was not used as a Money trial stimulus in the block immediately following its use as the No-go stimulus, to avoid retroactive interference effects.

3. Results

3.1. Participants' characteristics

The Harmful (Harm) and Non-Hazardous (NH) groups did not significantly differ on age, $F(1,84) = 2.4$, $p = .12$, years of education, $F(1,84) = 2.88$, $p = .10$, or years of alcohol use, $F(1,84) = 0.7$, $p = .38$, but did differ on the AUDIT total score, $F(1,84) = 474.9$, $p = .00$, average weekly alcohol consumption, $F(1,84) = 139.8$, $p = .00$ and gender, $X^2(1, N = 84) = 10.5$. $p = .00$. The Harmful group contained a significantly higher proportion of males and had a significantly higher AUDIT score and weekly alcohol consumption when compared to the Non-Hazardous group. Given the previous findings from Nederkoorn et al. (2009) and Scaife and Duka (2009), showing gender differences in the association between alcohol-related behaviour and cognitive control performance, gender was used subsequently used as a second factor in the analysis examining group status and task performance.

3.2. MI-GNG Task performance

Performance indices for each condition are presented in Table 2. A 2 group $\times$ 2 gender $\times$ 3 incentive condition (Neutral, DR, IP) ANOVA, indicated response inhibition performance was significantly influenced by incentive context, $F(2,162) = 22.6$, $p = .00$, but not group, $F(1,81) = .01$, $p = .90$, or gender, $F(1,81) = .13$, $p = .71$. Pairwise comparisons (Bonferroni corrected for multiple comparisons using LSD) of contingencies relating to control during No-go trials indicated that inhibition accuracy was significantly better in the IP and DR conditions compared to the Neutral condition, p's $< .01$, but IP and DR were not significantly different to each other ($p = .06$).

The interaction between gender and incentive condition, $F(2,162) = 1.5$, $p = .23$, and gender, hazard group and incentive condition, $F(2,162) = 1.7$, $p = .19$, were both non-significant. The interaction between hazard group and incentive condition was significant, $F(2,162) = 10.2$, $p = .00$, with the Non-Hazardous group showing a significant difference between all three conditions (IP > DR > Neutral; p's $< .01$), whereas the Harmful group showed significantly improved response inhibition accuracy for the IP and DR conditions when compared to Neutral (p's $< .01$), but IP and DR were not significantly different ($p = .09$). Similarly, pairwise comparisons indicate that during the DR condition, inhibition accuracy was significantly higher for the Harmful group when compared to the Non-Hazardous group ($p = .01$), whereas the opposite pattern was evident during the IP condition ($p = .05$).

Significant main effects of incentive condition were also found for Money, $F(2,162) = 4.56$, $p = .01$, but not Go, $F(2,162) = 1.6$, $p = .19$, trial reaction time (RT). Specifically, pairwise comparisons of Money trial-types revealed significantly slower RTs for the IP condition, in comparison to either DR or Neutral, p's $< .01$. Money and Go trial RT did not show a significant main effect of hazard group (Money: $p = .65$; Go Trial: $p = .66$) or gender (Money: $p = .62$; Go Trial: $p = .50$), nor an interaction between incentive condition and gender (Money: $p = .50$; Go Trial: $p = .56$), or incentive condition and hazard group (Money: $p = .38$; Go Trial: $p = .76$), suggesting that the differences in inhibition accuracy were not due to underlying differences in response speed.

4. Discussion

The results of the present study indicate that participants who currently consume harmful levels of alcohol have a reduced sensitivity to monetary punishment, which is associated with a significantly poorer ability to withhold their impulse for a rewarding stimulus. The harmful alcohol use (Harm) sample retained equivalent inhibitory control performance under neutral conditions

Table 2
Mean accuracy, reaction time and standard error scores for the Neutral, Delayed Reward (DR) and Immediate Punishment (IP) conditions on the MI-GNG task, for Harmful ($n = 30$) and Non-Hazardous Alcohol drinkers ($n = 55$).

Category	Neutral		DR		IP	
	M	SEM	*M*	SEM	*M*	SEM
No-go accuracy (% correct)						
NH	59.2	2.6	66.7	2.4	78.1	1.9
Harm	61.7	2.5	74.4	3.2	69.7	2.6
Money trial RT (ms)						
NH	339.6	7.7	345.1	8.9	363.4	8.7
Harm	346.8	10.5	362.8	12.1	368.2	11.8
Go trial RT (ms)						
NH	331.9	9.0	333.6	12.4	342.9	11.9
Harm	327.2	10.2	328.7	12.5	337.6	12.0

NH = Non-Hazardous, Harm = Harmful.

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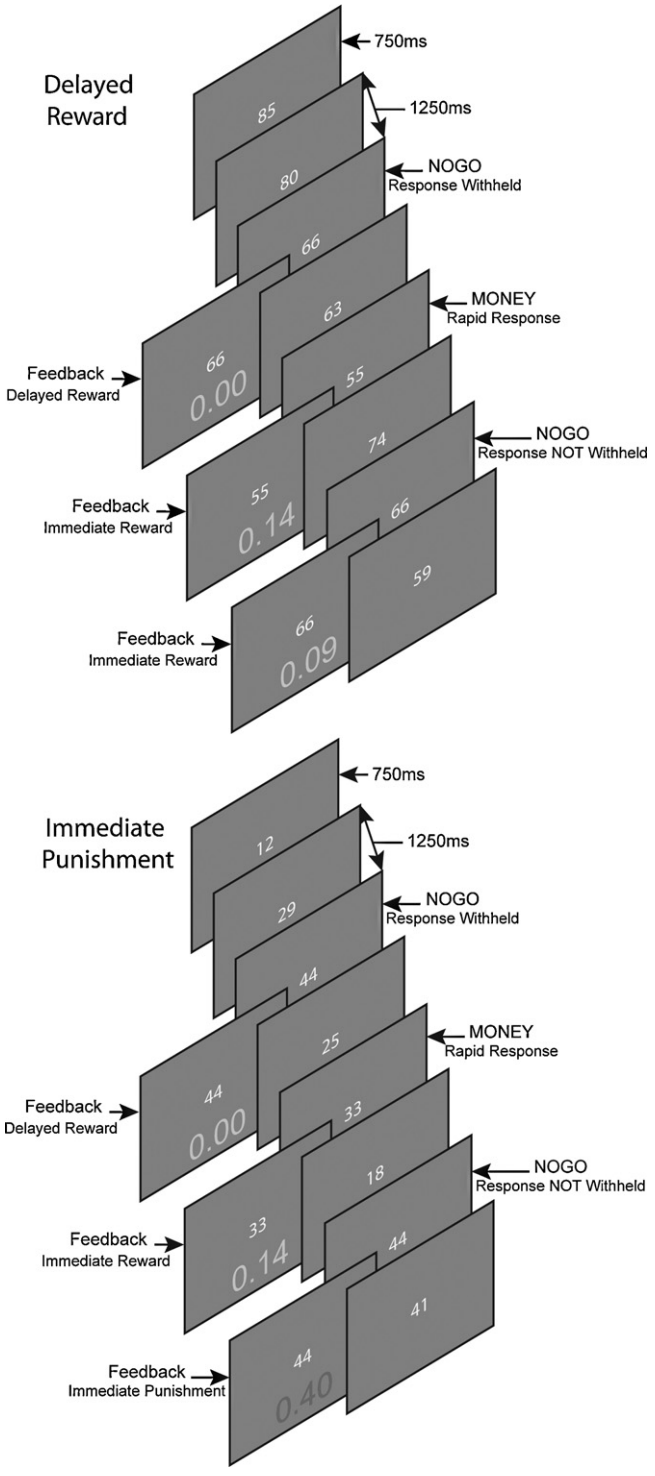

Fig. 1. Monetary Incentive Go/No-Go task design. The task required participants to (i) respond rapidly to different-digit double-digit numbers (Go trials); (ii) respond rapidly to same-digit double-digit numbers (Money trials) and (iii) withhold response to a designated same-digit double-digit number previously employed as a Money trial in the preceding block of trials (No-Go trials). Immediate feedback on Money and No-Go trial performance was provided on the screen. Feedback for response inhibition failure was contingent on condition: (i) Delayed Reward resulted in monetary reward commensurate with response speed; (ii) Immediate Punishment resulted in monetary punishment; (iii) Neutral resulted in neither monetary reward nor punishment.

(associated with neither monetary loss or gain) when compared to a non-hazardous alcohol consumption (Non-Haz) sample, ruling out a general impairment in inhibitory control. However, the imposition of an immediate monetary punishment for failed impulse control did not significantly improve their performance relative to the comparison condition (delayed reward). Similarly, the Harm sample's performance during the punishment condition was significantly poorer than the Non-Haz group.

The reduced sensitivity to monetary punishment in the Harm group is consistent with previous behavioural findings in dependent alcohol users (Bechara et al., 2002), other dependent groups (Ersche et al., 2005; Grant et al., 2000), and non-dependent users under the acute influence of alcohol (Loeber and Duka, 2009a,b). The results of the present study indicate that such a reduction in punishment sensitivity has a direct influence on impulse control for reward-related stimuli, and can be demonstrated in a non-dependent alcohol abusing sample.

Previous research with such non-dependent populations has identified impulsive decision making for reward, typically when using the delay discounting procedure (Bickel and Marsch, 2001; Field et al., 2007; MacKillop et al., 2011; McDonald et al., 2003; Mitchell et al., 2005; Monterosso et al., 2001; Petry, 2001; Vuchinich and Simpson, 1998), while others have failed to show such a deficit (Fernie et al., 2010; Kirby and Petry, 2004; MacKillop et al., 2007). Studies examining inhibitory control deficits in non-dependent alcohol abusing samples, with tasks such as the Stop-signal and Go/No-go (Colder and O'Connor, 2002; Kamarajan et al., 2005; Nederkoorn et al., 2009), have also failed to show response inhibition impairment, which lead Fernie et al. (2010) to hypothesize that such tasks may not be sufficiently sensitive to detect impulse control problems in non-dependent populations in the absence of punishment for inhibitory control failures. The results of the present study appear directly consistent with this hypothesis, insofar as the Harm group's response inhibition performance was not significantly poorer than the Non-Haz group during the neutral condition, which closely resembles a typical Go/No-go task. Furthermore, the Harm group's response inhibition performance during the delayed reward condition was significantly better than the Non-Haz group. The latter result appears analogous to a recent result from Chung et al. (2011), who demonstrated that immediate reward improved antisaccade task performance in adolescents with substance use disorder.

The specific task parameters appear particularly important in accounting for the effectiveness of a delayed monetary incentive in the current task for improving response inhibition for reward stimuli in non-dependent alcohol users. This particular result appears on face value to be inconsistent with the past studies showing the opposite tendency in non-dependent participants administered the delay-discounting task (Field et al., 2007; Vuchinich and Simpson, 1998). The inconsistency does not appear due to sample characteristics per se, for example, the AUDIT score of the current Harm sample is higher than that of Field et al.'s (19.4 and 15.3 respectively). The current task required participants to withhold their response to an immediately rewarding stimulus based upon speed of response, for a delayed monetary reward that was calculated according to the number of consecutive correct inhibitions over a series of No-go trials. On average, failing to inhibit was worth 20c per No-go trial, whereas successfully inhibiting was worth 40c per trial (the latter increased with greater control performance, and vice versa for poorer control). While the larger reward was delayed, the current task may have assessed control within a part of the discounting function that promoted delayed gratification. This has obvious implications for future cognitive studies in this sample, but also highlights that public-health or individual interventions, such as the Contingency Management approach that emphasizes greater delayed monetary rewards from continued abstinence (Olmstead

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and Petry, 2009; Petry, 2010; Petry et al., 2011), might still be effective in the non-dependent alcohol use population if the relative value of control is appropriately weighted.

The failure of monetary punishment to promote improved impulse control in the Harm sample also has both theoretical and clinical implications. Previous research has demonstrated reduced behavioural sensitivity to punishment in drug-dependent samples (Bechara et al., 2002; Ersche et al., 2005; Grant et al., 2000), with neuroimaging studies suggesting a potential mechanism being the influence of chronic drug use on both sub-cortical 'limbic' regions such as the striatum and cortical regions such as the anterior cingulate cortices. Both regions showed diminished neural response to monetary loss (Beck et al., 2009; Bjork et al., 2008a,b; Wrase et al., 2007), though the consequences of such a reduced loss-response to subsequent behaviour was unclear (Hommer et al., 2011). The current findings suggest that such behavioural punishment insensitivity can be demonstrated in a chronically consuming, but non-dependent, alcohol using sample, and that one consequence of this insensitivity is a reduced ability to control the impulse for immediate reward in the face of negative consequences. The latter is a core symptom of drug dependence and highlights the potential of cognitive tasks, which specifically assess impulse control in the face of punishment, to more sensitively predict those chronic drug users who are at risk of transitioning to dependence (Goudriaan et al., 2011; Rubio et al., 2008; Verdejo-Garcia and Bechara, 2009).

The current finding in non-dependent alcohol users appears consistent with the clinical effectiveness of contingency management for treating dependent populations, insofar as providing delayed monetary rewards (Olmstead and Petry, 2009) for successive days of abstinence improves long term treatment outcomes. The predictive validity of the current task, with its monetary reward and punishment format, for success in contingency management would be of particular interest. Similarly, the current findings may have implications for the recent positive findings for training response inhibition to decrease alcohol consumption (Houben et al., 2011), highlighting that reward-based, rather than punishment-based, contingencies during training may be the most efficient.

Recent human work has also demonstrated that reduced dopamine receptor density is associated with diminished behavioural and neural sensitivity to punishment (Klein et al., 2007), with administration of dopaminergic agonist further decreasing the sensitivity to punishment (and increasing the sensitivity to reward; Cools et al., 2009; Frank et al., 2004). While the exact relationship remains unclear, if the mechanism that links impulsiveness for reward with greater drug reinforcement, also simultaneously produces reduced sensitivity to punishment, then there would be clear negative consequences for vulnerability to addiction.

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Contributors

S.R., J.T. and R.H. developed the cognitive task, analysed and interpreted the data and co-wrote the paper. S.R. and J.T. recruited participants and administered the cognitive tests. All authors contributed to the drafts of the manuscript.

Conflict of interest

No conflict declared.

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